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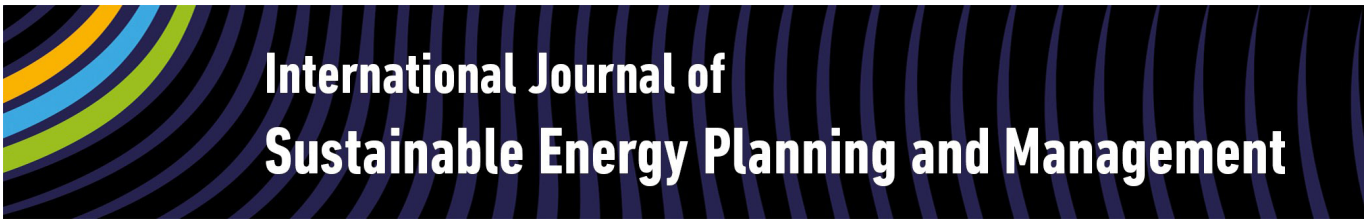

Consumer involvement in the transition to 4th generation district heating

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ABSTRACT

In the transition towards 4th generation district heating (4GDH), supply and demand side measures have to be coordinated better than in previous generations of district heating (DH). The heat demand of buildings has to be reduced, and heating installations as well as consumer behaviour have to be adapted so as to be compatible with and support lower network temperatures. It is therefore necessary to investigate and understand how consumers can be meaningfully and strategically included in the transition towards 4GDH. This paper provides a literature review of the consumer level's role during 4GDH in the transition towards 100% renewable energy systems. Current literature on 4GDH has been investigated to identify the connection and involvement of consumers in the transition. Even though consumers within the existing building mass have a large role in the transition in terms of heat savings and instalment of energy efficient technologies in the buildings, only a few publications address how these actions should be implemented at consumer level. From the results of the analysis it is recommended that further research should investigate how to strengthen the coordination between the supply and demand side in order to secure the right 4GDH initiatives are implemented in the right order.

Keywords:

4th generation district heating;
Low-temperature district heating;
Supply and demand side management;
Consumer involvement;

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1. Smart energy systems and 4GDH

Energy systems and the use of fossil energy resources are major contributors to the emission of CO_2 occurring all over the world [1]. Especially, energy consumption in buildings, transport and industry are of significance [2]. In 2014, a 2030 Framework for Climate and Energy was agreed upon by the European Council [3], containing three key targets: a minimum reduction in greenhouse gas emissions of 40% compared to 1990, minimum 32% renewable energy and a minimum 32.5% energy efficiency improvement [3]. On a national level, some countries, including Denmark, have committed themselves to creating a 100% renewable energy system in 2050 [4].

To optimally and cost effectively achieve 100% renewable energy systems, it has been advocated that the different sectors (electricity, heat, transport, gas) should be coordinated in a smart energy system where synergies between grids can be utilised to develop the best overall solutions for the energy system as well as for the individual grid or sector [5]. Heating is one sector that many policy makers have found difficult to address. Furthermore, the heating sector in many countries still heavily depend on fossil fuels, such as coal and natural gas.

The heating sector can play an important role for the integration of the different energy sectors in the energy system [6,7]. It is primarily in the Nordic countries (Denmark, Finland, Sweden) that largest shares of DH are visible in the energy systems [8], but also Estonia are starting to invest largely in DH [9]. In other countries such as UK, Germany, Italy, Netherlands, Slovakia and Hungary gas grids are largely developed and, finally, there are many countries, including Ireland, Spain,

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Portugal, where the heating sector is primarily developed around individual heating in the residential buildings. [8]

DH systems can utilize energy from various sources and convert them into hot water distributed in a pipe network. Since DH was introduced around 1880, it has gone through a major development [10]. From 1st generation DH based on steam to pressurised hot water over 100°C and later below 100°C, until today, where there is an ongoing transition from 3rd generation DH based on pressurised hot water below 100°C to 4th generation based on low-temperature water (<70°C) [10,11]. During recent years the concept of 4th generation DH has been developed in DH and smart energy systems research [5]. 4GDH has been defined as follows:

> *"4GDH systems are consequently defined here as a coherent technological and institutional concept, which by means of smart thermal grids assist the appropriate development of sustainable energy systems by providing heat and supply to low-energy buildings with low grid losses in a way in which the use of low-temperature heat sources can be integrated with the operation of smart energy systems. The concept involves the development of an institutional and organizational framework to facilitate suitable planning, cost and motivation structures." [*[5]*, p. 137]*

4GDH is one of the key elements for more efficient energy systems, due to its possibilities to utilize renewable energy sources in a more efficient way leading to e.g. a decrease in heat losses in the district heating network [12–14]. Low-temperature DH – i.e. lower DH network temperatures – is a central element in 4GDH because it supports the integration of low temperature heat sources and improves the energy efficiency of the energy system [15]. Low temperature DH can be implemented, both, in new building sites that are being prepared and developed as well as in the existing building mass with the difference that existing buildings may have to undergo more far-reaching energy efficiency upgrades in order to be compatible with lower DH temperatures. Low-temperature DH is defined as;

> *"Low Temperature District Heating (LTDH) system is defined as a system of district heat supply network and its elements, consumer connections and in-house installations, which can operate in the range between 50-55ºC supply and 25-30ºC to 40ºC return temperatures and meet consumer demands for thermal indoor comfort and domestic hot water." [* [16]*, p. 9]*

Following from the above, 4GDH represents a paradigmatic shift in the interaction between the supply and the demand side in the district heating system. Lower supply temperatures increase the DH system's vulnerability to fluctuations in production and consumption, necessitating careful planning and operation.

Buildings and building installations need to be adapted in many cases in order to operable with lower supply temperatures, and in turn, supporting the actual lowering of the supply temperature [17]. Implementing low-temperature DH in the existing building mass requires more than in new areas in terms of technical solutions that allow the temperature to be lowered in the DH network [12]. This also includes short-term and long-term behavioural changes at the level of homeowners, including investments in different energy improvements that increase the buildings' compatibility with low temperature DH [18].

In Denmark, it is estimated that the heat consumption in existing buildings should be lowered to 80 kWh/m^2 by 2050 which is equal to around 40% reduction in the heat demand, while it is sufficient in new buildings to maintain a heat demand of around 55 kWh/m^2 [19–21].

Research within 4GDH and low-temperature DH has so far mainly focused on the new technical components in and the system configuration of the DH network and new building mass [22–25]. However, the existing building mass has one of the largest energy efficiency improvement potentials within the energy sector [26].

In this paper, the focus is on the existing building mass and how homeowners can be motivated and supported to prepare their homes for low-temperature DH and 4GDH. A new coordination challenge arises here, because building-level efforts have to be coordinated strategically to enable the conversion of neighbourhoods of existing buildings to low temperature DH – and in order to avoid single buildings becoming a barrier for the roll-out of low-temperature DH. As a consequence, the interaction between supply and demand has to be intensified and made more strategic. It is, thus, relevant to investigate to what extent the existing literature on 4GDH deals with this issue.

The paradigm shift to smart energy systems and 4GDH requires a change in the current approach of the planning and implementation within the heating sector development in order to secure the most optimal system design without over-investing in (oversized) infrastructure. This is emphasised by Hvelplund et al. [20];

" […] to synchronize the right amount, in time and of the right types of investments in heat conservation with investments in the energy supply system." [[20], p.1]

Apart from that, in order to achieve low-temperature DH it is necessary to think and coordinate across different professional competences. For instance, implementation of low-temperature DH can have a negative effect on the indoor climate if the existing building mass do not go through the proper energy restoration. Therefore, it is relevant to investigate how the connection between the transitions to 4GDH and actions at the consumer level have been addressed in current scientific literature. This leads to the formulation of the following the research question for this paper:

What is the status of the current research on consumer involvement in 4GDH and implementation of low-temperature district heating?

1.1 Structure of the paper

The research question is answered through a literature review where 4GDH literature is examined with a specific focus on the consumer level. The literature review is supplemented with knowledge from real-life cases that are working or have worked with the consumer level in the transition to 4GDH. The paper consists of four sections. The second section presents the methodology used in the paper. In section three the results of the scientific literature review are presented, which is followed by section four, where preliminary insights from the identified real-life cases are summarized. Finally, the conclusions of the analysis are presented in section five along with recommendations to further research.

2. Methodology

This paper is based on a literature review of scientific publications identified in searches on the two databases ScienceDirect and Scopus. There are numerous papers available when searching for papers within the search criteria; "4th generation district heating" and low-temperature district heating". A total of 2.273 papers were identified using the two search criteria in ScienceDirect and Scopus.

The searches reveal that the papers date back to 1996, but the majority of the papers are from 2010 and forward. The high number of papers within the topic along with the increase in papers during the last 10 years, indicate that this is a topic that has been gaining scientific interest during the recent years.

In 2018 Lund et al. [11] published a literature review summarizing the state-of-the-art of 4GDH. In their paper Lund et al. include a total of 298 papers within the scope of 4GDH [11] and from their results it is clear that the primary focus in 4GDH research is on the technical development of the DH system and actions that are required to prepare the DH grid for low-temperature DH [11]. This literature review differs from Lund et al.'s study, in the sense that this paper has a more detailed focus on the involvement of the consumer level in 4GDH and low-temperature DH. The authors did not find other scientific publications with this focus, which makes this article a novel contribution to the emerging 4GDH literature.

Lund et al. [11] identify a strong focus on the technical elements in the 4GDH literature and along with the increase in scientific papers within the subject, it is therefore important to also identify some of the (non-technical) potentials in the transition towards smart energy systems and 4GDH in order to guide further research and the practical transition to 4GDH.

To narrow down the number of papers included in the literature review to papers that address the consumer level in the transition to 4GDH a number of different search criteria were defined, see Figure 1. Figure 1 illustrates the work process in the literature review.

The search for papers resulted in 464 papers with the selected search criteria. After elimination of overlaps in between searches the number of identified papers was narrowed down. The search for papers in ScienceDirect included papers containing the search criteria in the complete paper. Subsequently, papers not mentioning the search criteria in the title or abstract were eliminated from the study. This resulted in a total number of 82 papers to be included in the further assessment. The more detailed examination of the 82 papers, revealed that most of the papers only mentioned the consumer level briefly without further addressing or investigating it directly. Thus, only 28 papers were included in the actual literature review Figure 1.

4GDH is a relatively new term within collective heating and it can be assumed that relevant learnings, in terms of consumer involvement in DH literature in a more general perspective can supplement the findings of the literature review of consumer involvement in 4GDH. Therefore, an additional literature search in ScienceDirect on ("District heating" AND ("Consumer involvement" OR "User involvement")) has been added to identify important learnings that can be transferred into the implementation of 4GDH in local societies.

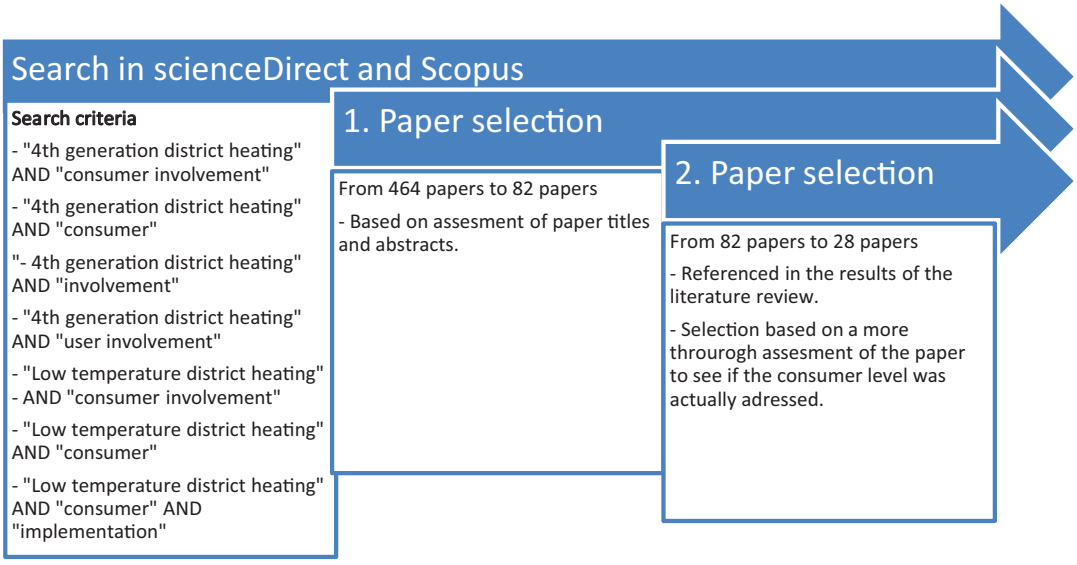

Figure 1: Methodology overview for the selection of reviewed papers.

This literature search resulted in a total of 38 papers, out of which 9 were relevant to be included in this paper.

3. Results of the literature review

The results of the literature review are divided into three sections, where the first section is based on the literature on consumer involvement in DH in general. The second section is based on literature addressing the supply-side in relation to 4GDH and in the third section the demand-side focus in relation to 4GDH is presented. Finally, the results are summarized to highlight identified topics in the 4GDH literature.

3.1 Consumer involvement in district heating in general

The literature review on consumer involvement in district heating in general shows that, consumers are primary mentioned in publications after 2009, and often in a broader perspective then only DH, such as the transition towards smart energy systems [27] and climate targets [28].

Heat consumers are primarily mentioned in three different ways. 1) End-users with no interest in DH [29], 2) end-users with no importance for the DH development [29] or 3) Important players in energy transition and there is a need for more consumer involvement [30–33].

Several studies indicate the importance of involving the consumers, such as Walnum et al. [28] who state that just because users have access to decision-support tools it is not given that they will adapt these and therefore, is it important to involve different stakeholders, including users, in the development of such tools in order to secure an acceptance. Furthermore, Valkila and Saari [34] indicate that even though, the consumers are aware that they need to reduce their energy consumption, they hesitate to do so because they are too "comfort-loving" to take any actions.

However, one example of consumer involvement in terms of ownership can be seen in the Danish case of DH. District heating in rural areas in Denmark has a history of being consumer-owned with 341 consumer-owned DH companies in 2016 [35]. Gorronõ-Albizu et al. [35] indicate that the large amount of consumer ownership of Danish DH is due to the "non-profit-rule" that sets limits for profit accumulation in DH companies and requires DH companies to pay any excess profit back to the DH consumers. It is therefore, the consumers, as owners, that have an interest in the organization and economy of the DH company in order to secure low DH prices.

Even though several studies point at the importance and need for more consumer involvement, no papers have been identified which present cases or suggestions for how this DH consumer involvement can happen in a

practical way. One reason can be that DH is not widely developed outside the Nordic countries. Furthermore, since DH until now has been delivered at relatively high water temperatures, the sensitivity of DH systems has been low making it unnecessary for consumers and suppliers to investigate (4GDH) demand side measures, apart from saving money on DH consumption.

3.2 Supply-side in 4GDH

Overall, the literature review shows that the primary focus in the identified literature is directed at a technical level. The main technical topics addressed in the literature on consumer involvement in 4GDH are: *temperature*: i.e. how much can the temperature in the DH network be lowered without causing any health or comfort issues [12,36]; use of *new and fluctuating heating sources* such as waste heat from industry, biomass, solar thermal, geothermal, sewage water etc. [14,26,37,38]; as well as the *combination of different energy sources and thermal storage* to increase the efficiency and reduce the CO_2 emissions from energy production [39,40].

Also, many studies analyze the DH systems using different models, TIMES [37,41] Balmorel [26], TRNSYS [42,43]. These models rely on e.g. production and demand inputs, which for the demand-side often are based on assumptions and forecasts [44].

3.3 Demand-side perspective in 4GDH literature

The identified literature that has a demand side focus often frames the consumer level in terms of technical obstacles to 4GDH [10,45–47]. One example of barriers for the transition at the demand-side is that consumers heating devices are designed for higher temperatures [48]. Another reported barrier is the need for technical measures in individual buildings (e.g. new radiators, insulation of houses, energy efficient windows, mechanical ventilation [26] [49]).

Blumberga et al. study the challenges related to the development of renovation projects in different European countries [50]. They find even though different grant schemes are provided from the European Union and local governments' renovation of the building mass is still happening at a slow pace. Consumers should understand the benefits and importance of improving energy efficiency and renovating their buildings and, therefore, thorough communication with homeowners is an important instrument [50].

Nord et al. [25]point out that the existing building mass should undergo improvements to be capable of fitting into a 4GDH network. Furthermore, the fact that the heating devices in buildings are not being operated in optimally results in high return temperatures from the consumers, which is a challenge for the development of 4GDH [25]. In relation to demand-side management, it is highlighted that technical installations such as the radiators´ heat transfer surfaces need to be increased to allow the DH supply temperatures to be lowered, while still securing the right comfort level for the consumers [12,51]. Zhang et al. [52] recognize the importance of the consumers in the transition to integrated flexible energy systems, however even view the participation of consumers as a disadvantage, without going further into detail [52]. One of the important actions mentioned for the consumer level is the reduction of energy consumption for space heating [26]. Some studies argue that it will require large investment costs to reduce heat demand in existing buildings [53], especially if the investments are not made in relation to already planned renovations of the existing building mass [19–21]. Lund et al. [10] argue that demand-side management could be improved through education of craftsmen for them to be able to understand and handle the coordination of different components in smart energy systems..

Nuytten et al. [39] emphasize that flexible energy systems that combine heat and power require focus on demand-side management and the flexibility the demand-side can provide in these "new" energy systems. Interestingly, Nuytten et al. [39] argue that this demand-side flexibility can be achieved through centralized and decentralized thermal storage [39]. Paiho and Saastamoinen [54] investigate challenges and opportunities for district heating in Finland and point at the consumers lack of knowledge and interest in DH as one of the most important challenges for the development of DH. Thus, consumers should be more strongly involved in this sector. Other studies highlight municipalities as an actor that should an obvious motivation to better involve DH consumers [50] and/or become frontrunners through development of pilot projects [54].

Even though, several obstacles for 4GDH are identified in connection to the consumer level, only a few papers are identified which directly address consumer or user involvement in relation to 4GDH or low-temperature DH [20,43,55]. Hvelplund et al. [20] discuss necessary incentives for energy conversation in existing rental

buildings and apartments. They conclude that it is important that all house owners have posibilities to make the needed investments in energy conservation, and suggest incentives that combine of 100% variable DH tariffs and guaranty for 30-year loans with a low interest (2%) [20]. These suggestions are supported by Djørup et al. [56] who show how 100% variable tariffs and low interest loans can help close the gab between the economic and private economic optimum of heat savings in single-family houses in a 4GDH system.

Volkova et al., discuss in [55] and [9] the importance of consumers for the transition towards low temperature DH. For this purpose, they [55]introduce a mobile app as a tool that should improve DH consumers' level of information and motivation through access to basic information about heat consumption; comparisons with other heating sources; and display of how different behavioural changes affect the heat consumption and CO_2 emissions.

3.4 Summary – results of literature review

The reviewed literature covers several topics related to the transition to 4GDH for, both, the supply-side and demand-side. These topics are summarized in Table 1. Table 1 is a snapshot of the topics addressed in the scientific literature in relation to consumers' role and involvement in 4GDH. In general, it appears that a) a stronger involvement of DH consumers and the demand-side is acknowledged in the existing literature; b) there is (some) knowledge of the technical adjustments and measures supporting 4GDH at the consumer level; c) however, a further or more direct involvement of consumers either is not yet researched further, (too) difficult or even counterproductive. This suggests that the 4GDH literature has not (yet) been taken to the "next level" outlined in the introduction: analysing and proposing how specifically DH consumers can be supported and involved in 4GDH, i.e. the "what works and what does not and why" in

Table 1: Summary of identified topics in the reviewed literature.

Identified topics through literature review			
Supply-side topics	**References**	**Demand-side topics**	**References**
Storage units/systems	[39,57]	Old Heating devices designed for high supply temperatures	[10,45–47]
Temperature (low temperature opportunities	[12,36]	Old Heating devices designed for high supply temperatures	[48]
Heat sources (new and fluctuating)	[14,26,37,38]	Need for individual actions and investments in new heating devices and/or energy saving measure$_s$	[12,25,26,49,51]
System optimization (combination of energy sources and heat storage)	[39,40]	Slow renovation rate of existing buildings due to lack of or wrong communication with the homeowners	[50]
Energy models	[26,37,41–43]	Wrong operation of heating devices	[25]
Demand based on assumptions and forecasts	[44]	Consumer involvement important in the transition to 4GDH	[52,55]
		Consumer involvement a disadvantage in the transition to 4GDH	[52]
		High Renovation investment cost	[19,20,53]
		Right education of craftsmen	[10]
		Flexibility at the demand-side can help the implementation of flexible energy systems	[39]
		Lack of knowledge and interest among consumers	[54]
		Need for consumer involvement	[54]
		Municipalities important actors as frontrunner or motivator	[50,54]
		Mobile app as a tool to motivate consumers	[9,55]

relation to adopting 4GDH measures from a consumer perspective.

4. Consumer involvement in 4GDH R&D projects

This section takes a brief look at a few completed and ongoing development and demonstration projects within the field of consumer involvement and 4GDH – within the Nordic context. The purpose is not to draw a complete picture of the non-academic literature within the field, but rather, to see if examples of concrete 4GDH practices and projects can point to some issues that do not necessarily emerge from the academic literature, and thus, to supplement this literature.

4.1 Combining building retrofits with low-temperature DH

Between 2010 and 2014 the Danish Energy Technology Development and Demonstration Programme (EUDP) as well as the Danish District Heating Association funded a number of pilot projects on low-temperature DH within existing DH supply areas and buildings [58]. In one of the projects, focus was on a small number of detached, single-family houses with the aim to reduce DH grid losses by means of renovating the DH distribution grid, the houses and lowering the supply temperature. The results confirmed that it is not enough to renovate the building envelope in order to be able to reduce the supply temperatures, but that the renovations should be combined with an installation of new radiators with increased effect [58]. In terms of consumer involvement, the project showed that it proved to be difficult for the local utility company to motivate the building owners to retrofit their buildings even with information and energy audits carried out by the utility company and access to subsidies for building retrofits [58]. Another issue raised in the project was that lowering the supply temperature should be done in close communication with consumers to not risk decreasing their comfort level, which may lead to suboptimal investments in additional heating sources, such as heat pumps or wood stoves, which would somewhat counteract the improvement of the DH system [58].

In another project, deep renovation of council flats together with a modernization of the DH grid at the building level was demonstrated in Albertslund Municipality. Starting with a few pilot renovation projects, until 2015 590 council flats and their DH network were modernized to accommodate low-temperature DH, and achieving up to 60% reduction in net heat demand [59]. The project was based on a close cooperation between the housing association (Bo-Vest), technical partners, the municipality and the residents. For instance, individual renovation preferences within an allocated budget were taken into account and a residents' satisfaction survey was carried out. Albertslund was based on this "Albertslund Concept" appointed "Nordic Energy Municipality" 2011 by the Nordic Council [60]. This is a case of an association of council flats, which, amongst others means that there was a centrally organized expertise and investment capacity and possibility to achieve economies of scale benefits. In terms of consumer involvement, it appears that citizens did not have to collect their own information and make own investment decisions but were involved in a guided and strategic way.

These two examples indicate that communication between DH consumers and DH suppliers / organizations responsible for building refurbishment should be made "easy", well-guided and improve the actual decision competences of consumers. The examples also highlight the transition to 4GDH cannot "just be done" by the DH suppliers without close communication with the consumers. One issue for future research that emerges is to what extent consumer involvement can and should be different in housing associations (with centralized investment decisions) as compared to single-family houses, where investment decisions and coordination of DH supply and demand happen at the level of the individual building owners [59,60].

4.2 App- and display facilitated energy consumption feedback

The Danish electricity supplier and distributor Seas-NVE has developed a free mobile phone app, called WATTS, to enable consumers to monitor their electricity consumption based on hourly smart meter data [61]. Several other energy supply companies have joined a collaboration with SEAS-NVE with the objective to develop the app such that it can several types of consumption (electricity, heat, gas, water).

One of these companies is Aalborg Forsyning (Aalborg Utility company), who in 2019 launched the app among 15,000 consumers [62]. The app allows consumers to follow their DH consumption hourly, daily, weekly and quarterly as well as their expected heat

consumption use based on their consumption in previous years. Users can see their DH costs and are presented with a budgeted DH consumption based on previous consumption patterns. Colors – green, yellow or red – when users are below, within or above their budgeted consumption. The app is being deployed and developed continuously and the goal is to expand the service to include strategic and long-term communication around energy savings and transition to 4DH.

In the Danish town of Frederikshavn, the local housing association has combined deep energy retrofits of their buildings with the installation of real-time displays in each apartment. The panels show information on tenants' energy consumption and give feedback using smiley icons – similar to WATTS [63]. While WATTS targets building owners, this display system, so far, is only available in rented apartments.

5 Concluding discussion – what can we learn?

The aim of this paper was to examine, what the status of the current research, on consumer involvement in 4GDH and implementation of low-temperature district heating, is. The literature review reveals a significant focus on the demand-side, as seen in Table 1. The literature especially addresses the technical design of 4GDH systems and points out measures that needs to be addressed at the demand-side in order to enable lower temperatures on the supply-side. The existing research provides important knowledge regarding the design of 4GDH systems in general, however, so far, not many insights are provided on how DH consumers should be involved in the actual implementation these demand-side measures in their own homes.

The existing building mass is responsible for 40% (2016) of the energy consumption in Denmark [64] and it is therefore important that research within the development and implementation of 4GDH, begins to take the concrete implementation possibilities and challenges into account. A new feature of 4GDH compared to previous DH set ups is that the demand side is becoming more critical for the operation of the whole DH system – e.g. in terms of network temperature levels. It has therefore become essential to understand how to involve consumers and develop the right policy measures for the transition to 4GDH.

One of the main points to take away from the literature study is the importance of the coordination between the supply-side and demand-side in 4GDH. For DH consumers this means that there is a need to renovate old heating devices and to update consumers' knowledge to ensure optimal operation of (new) heating installations. These short-term measures need to go hand in hand with more strategic actions regarding heat demand reductions through e.g. energy efficient building renovation. High renovation costs and low levels of interest and knowledge among DH consumers are pointed out as important barriers to these measures in the literature. At the same time, research on these specific aspects is only beginning to emerge. Generally, there is a gap in the existing literature regarding the connection between consumer actions, involvement and motivation and the transition to 4GDH.

To improve the level of information reaching consumers, Lund et al. [10] suggest that education of craftsmen regarding the specific demand-side technologies and components 4GDH and smart energy systems [10]. This could lead to better practical recommendations to consumers in terms of operation of heating devices and energy efficient renovations of buildings. This, along with mobile-apps, such as the one described by Volkova et al. [55], as a tool to promote changes in the consumer behaviour through access to information about their heat consumption, are some of the few identified papers that begin to develop tools and recommendations for concrete consumer involvement in terms of demand side measures in 4GDH. At the level of utilities, a similar development can be seen, for instance, at SEAS-NVE with their WATTS app giving consumers access to follow their electricity and heat consumption. As a next step, it will be relevant to investigate how these new information systems can incorporate 4GDH elements, such as information on DH temperature and long-term building energy efficiency – in addition to behavioural changes. A need for better interaction possibilities between DH suppliers and DH consumers could arise and be included in the further development of mobile apps and similar tools. Here also, the existing research on building energy efficiency and renovation can be of inspiration (Andrea Mortensen [65], Kirsten Gram-Hansen [66–68]), showing, for instance, how consumers can be motivated to adapt behaviour and investment decisions for better building energy efficiency. The missing link and a topic for further research is, however, the concrete application and adaptation of building energy efficiency research to 4GDH – i.e. including the supply side perspective. Similarly, the field of Human-Computer Interfaces (HCI) and eco-feedback technology can be of inspiration. HCI

research indicate that people with a general interest in technology and energy consumption are enabled by feedback on their energy consumption e.g., through smartphone apps and smart meters. However, for the majority of consumers, information to changing behaviour is not sufficient, but must fit with peoples actual practices which are often less focused on managing energy consumption [73]. As such the majority are less willing to manage their energy use actively and more willing to invest money in long term energy renovation to overall reduce their overall consumption (e.g., smart automation) [69–72]. However, to support long term decisions, recommendations on long term investments based on consumer energy consumption is important. Towards this end, Svangren et al. [73] found that householders' energy literacy is limited with respect to making informed decisions about building renovation and Hasselqvist et al. [70] found that displaying and recommending for long term investments had a positive effect on informing collective's decisions in energy renovation.

The identified real-life projects show that actors working with the implementation of low-temperature district heating in practice are starting to recognize the importance of connecting energy saving measures in the building mass with the implementation of low-temperature district heating. This can e.g. be seen through a focus on the consumer level in the demo projects. Here, the challenge is to transfer this knowledge to less "uniform" consumer groups in the DH system, such as single-family homeowners.

To sum up, we identify and recommend the following topics for further research on consumer involvement in 4GDH:

- Further develop IT tools (mobile apps etc.) to better link the demand and supply side, through e.g. improving availability and exchange of information on a specific building's performance, role and possibilities in a 4GDH system
- Collecting and synthesizing practical knowledge on the integration of building renovation and 4GDH (e.g. low temperature DH) obtained in real-life projects. Transferring this knowledge to "difficult" groups, such as the single-family building group.
- Linking building energy efficiency research with a consumer focus to 4GDH research
- The influence of different organizational and ownership models on DH demand and supply side coordination [20], together with the design of economic incentives (subsidies, tariffs, loan conditions etc.) [74]

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